

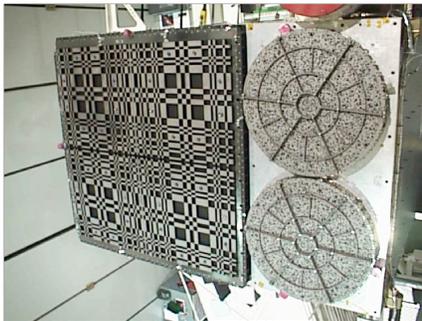
# ***The Nuclear Spectroscopic Telescope Array (NuSTAR)***

Observations of Cluster Non-thermal Emission  
AGN Surveys

Fiona Harrison  
Caltech

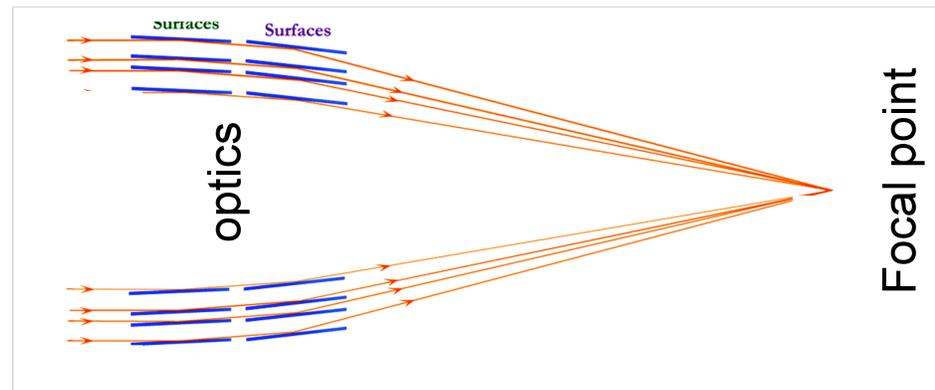
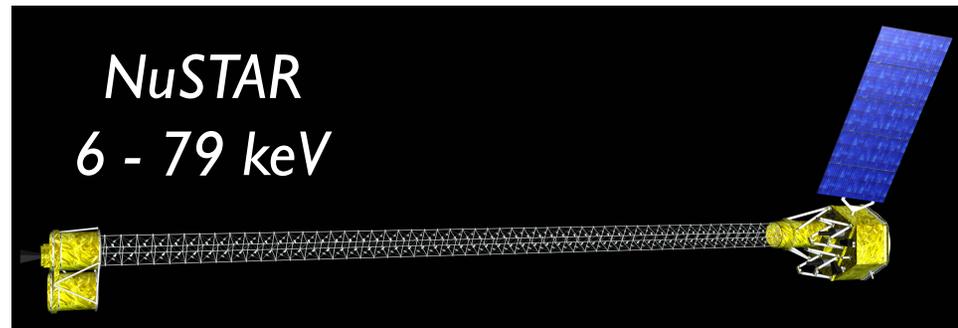


# Small Explorer Mission



Coded Aperture

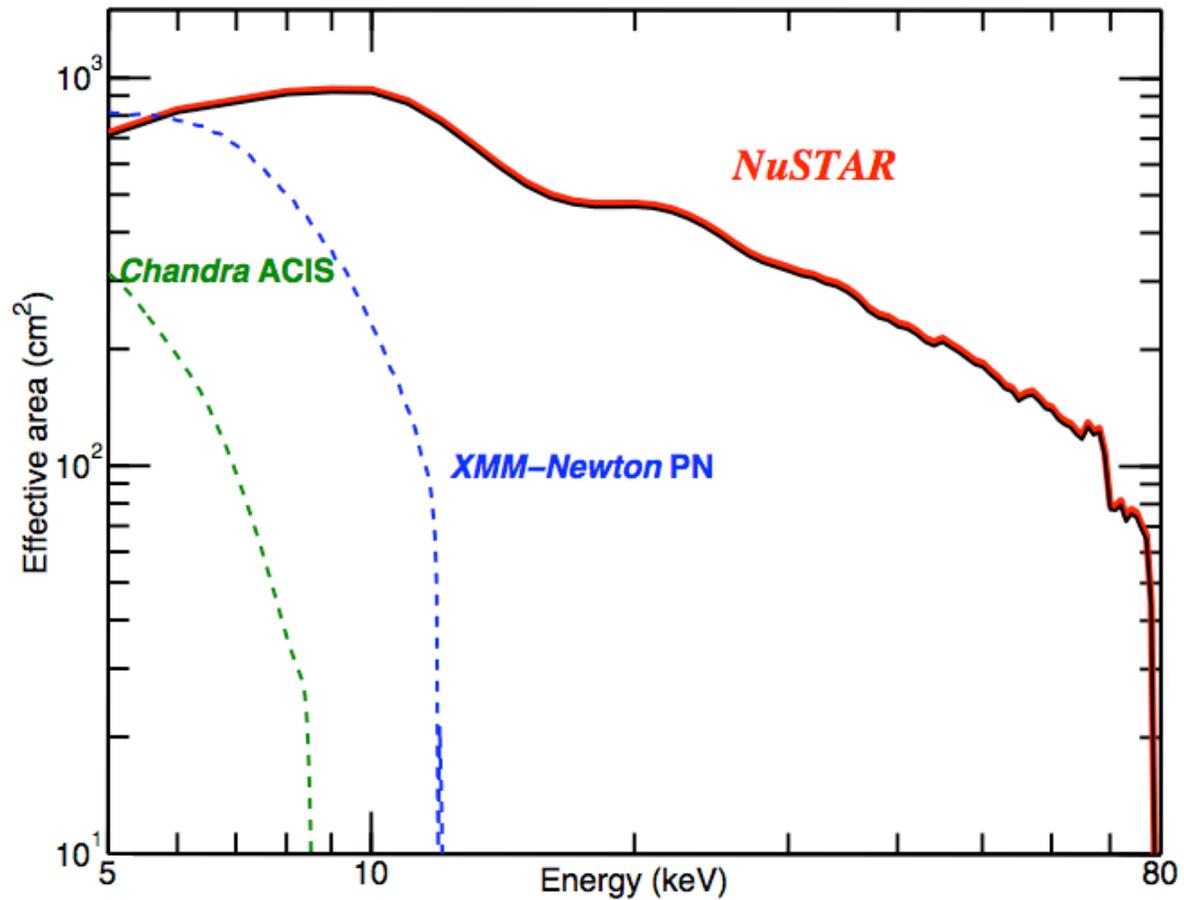
Launch August 2011



Focusing Telescope



# Extend focusing to high X-ray energies



Extends focusing to energies beyond Chandra and XMM



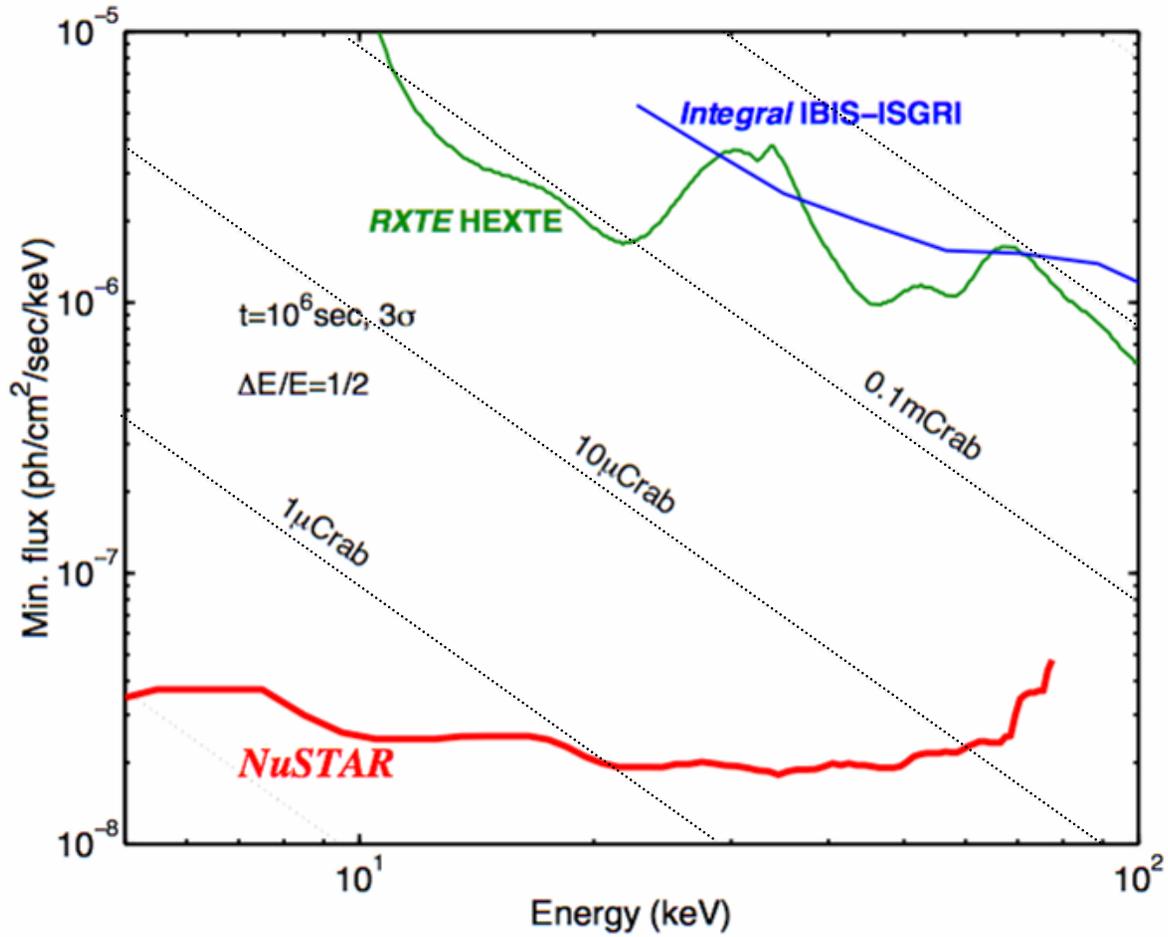
## Capabilities Summary



Energy band	6 - 79 keV
Spectral resolution	1 keV (FWHM) @ 60 keV 600 eV @ 6 keV
Angular resolution (HPD)	40 arcsec
Field of View	13.6 arcmin (10 keV) 11 arcmin (40 keV)
Temporal resolution	10 microseconds
Saturating count rate	250 cts/s in HPD
Effective area	900 cm <sup>2</sup> @ 10 keV 70 cm <sup>2</sup> @ 60 keV



# Point Source Sensitivity





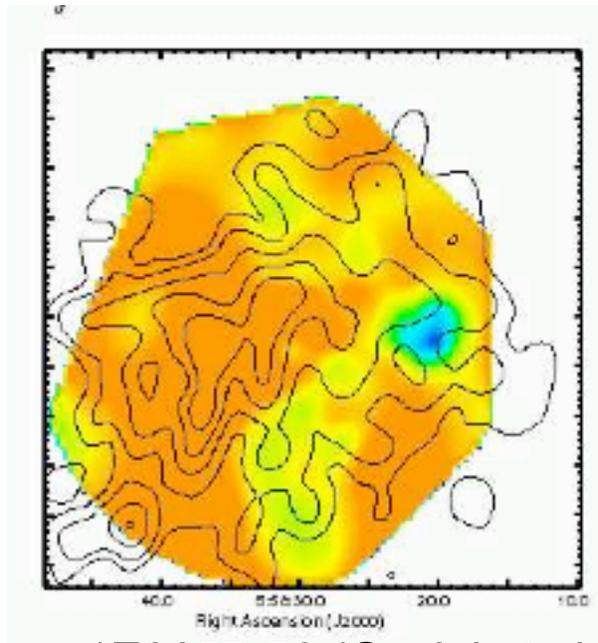
# High Energy Emission From Clusters



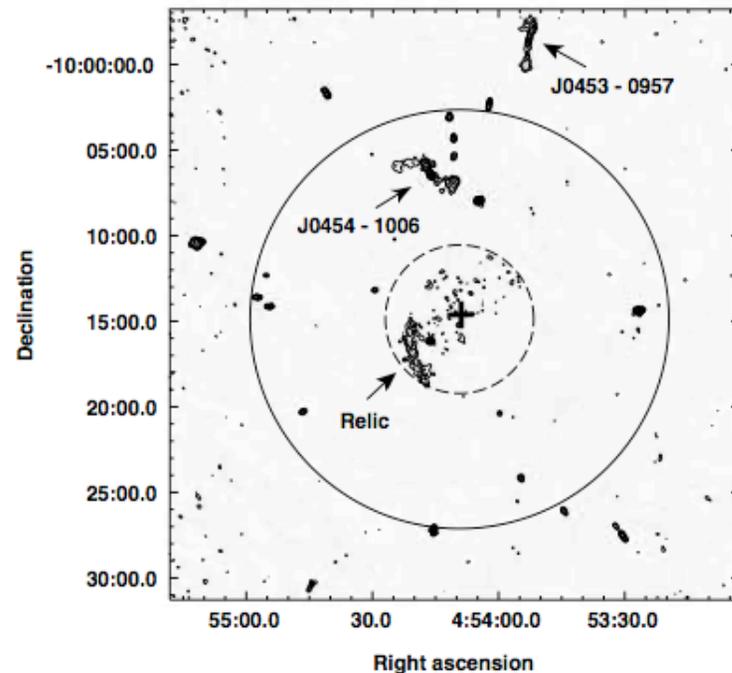
Particles can be accelerated to relativistic energies in merging clusters

steep spectrum radio sources

Processes include turbulence (halos), high Mach number shocks (relics)



1E0657-56 (Govini et al.)



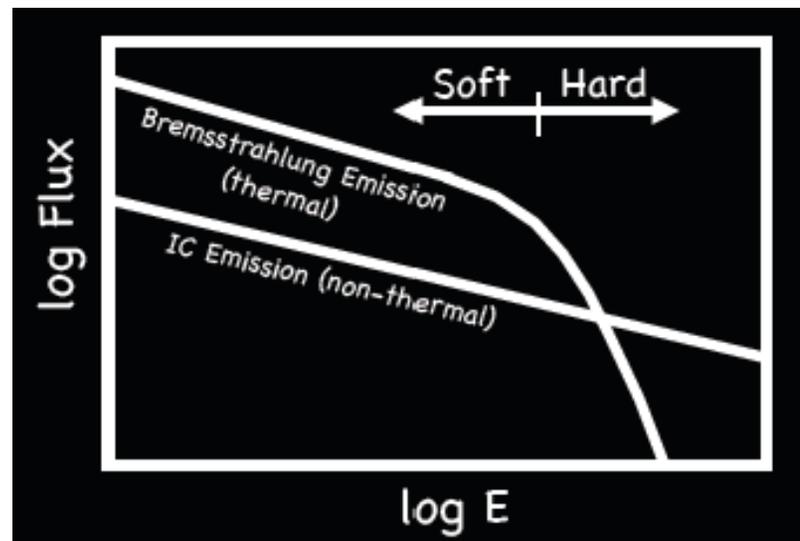
A521 (Giacintucci et al.)



## *Non-thermal Emission*



- Non-thermal component (particles and magnetic field)
  - Is tied to the formation history of the cluster
  - Pressure and energy content may not be negligible
- Magnetic field and relativistic electron density can be measured using high energy X-ray observations ( $E > 10$  keV)





## *Observations to-date*

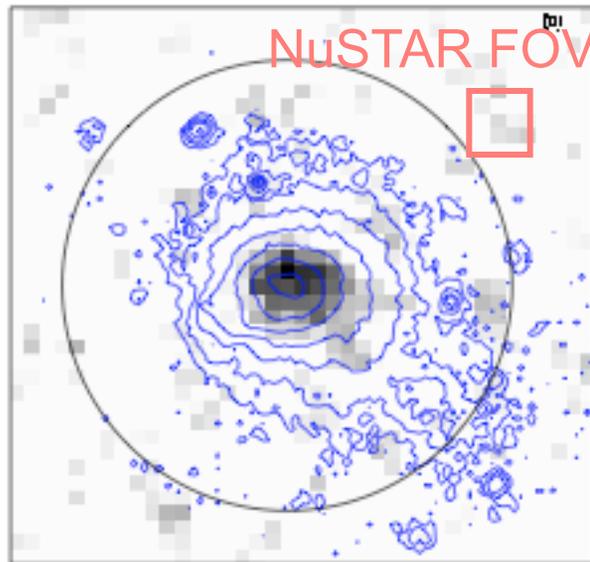


- **Detections of non-thermal emission**
  - Halos: Coma (SAX, RXTE - disputed), Ophiuchus (INTEGRAL), A754 (SAX - disputed)
    - Complicated by coarse or no imaging, limited sensitivity
  - Relics: A85 (ROSAT), A2034 (Chandra)
    - Background from thermal emission still important
- **NuSTAR observations**
  - Sensitivity 6 - 80 keV covering thermal and non-thermal emission
  - Spatial resolution to map diffuse emission and remove contaminating point sources



- Claimed detections/limits

- $\sim 1.5 \times 10^{-11}$  erg/cm<sup>2</sup>/s (20-80 keV) SAX, RXTE
- $< 7.8 \times 10^{-12}$  erg/cm<sup>2</sup>/s (20 - 80 keV) Suzaku [Sarazin]



Covering the central 30' in  $10^5$  s pointings:

$F_{\min} = 1.1 \times 10^{-12}$  (20 - 70 keV) for perfectly uniform diffuse emission (worst case)

Integral IBIS (17-29 keV)

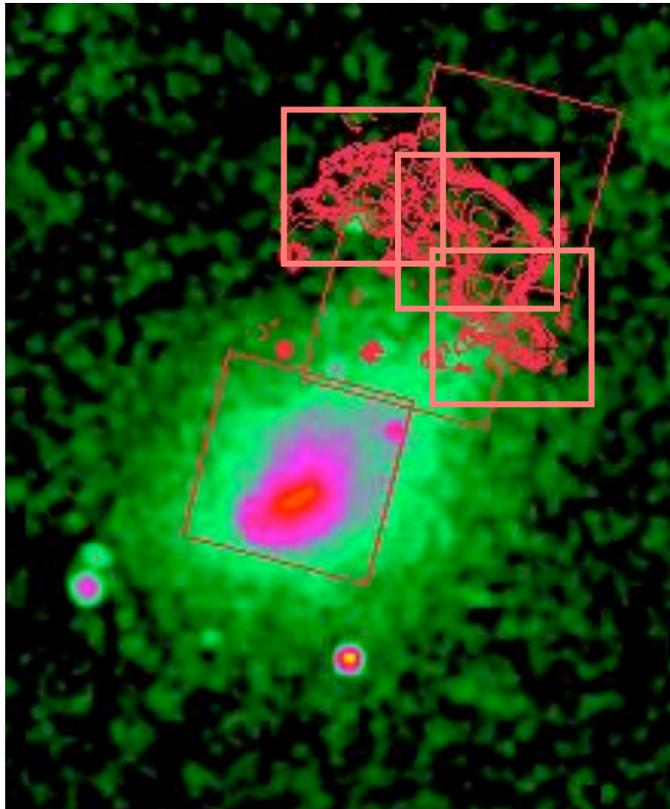
Lutovinov et al 2008



A3667



$F_x < 9.4 \times 10^{-12}$  ergs/cm<sup>2</sup>/s 12-70 keV [Suzaku XIS+PN]



NuSTAR

Three  $2 \times 10^5$  s observations

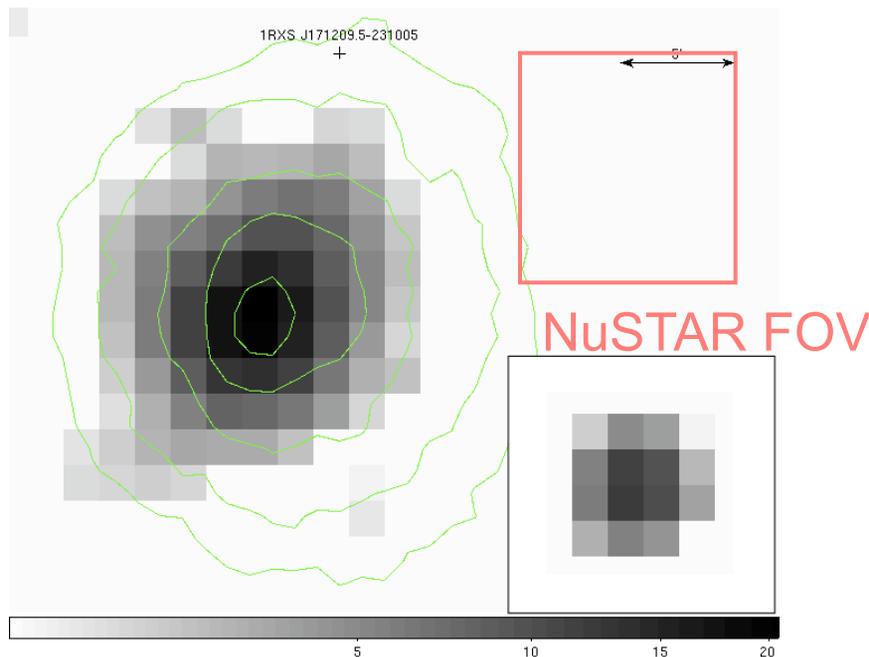
$F_{\min} = 7 \times 10^{-14}$  erg/cm<sup>2</sup>/s (10 - 40 keV) if follows radio contours



# Ophiuchus



- No evidence for merger - origin of HXR emission a mystery
- Integral IBIS detection:  $F_x = 1.0 \times 10^{-11}$  ergs/cm<sup>2</sup>/s (20-60 keV) [Eckert et al 2008]



NuSTAR four  $2 \times 10^5$  s observations

$F_{\min} = 3 \times 10^{-13}$  erg/cm<sup>2</sup>/s/keV (20 - 60 keV) assuming a uniform source with  $r = 6$  arcmin

JEM-X (3-18 keV) with ASCA contours  
Eckert (2008)



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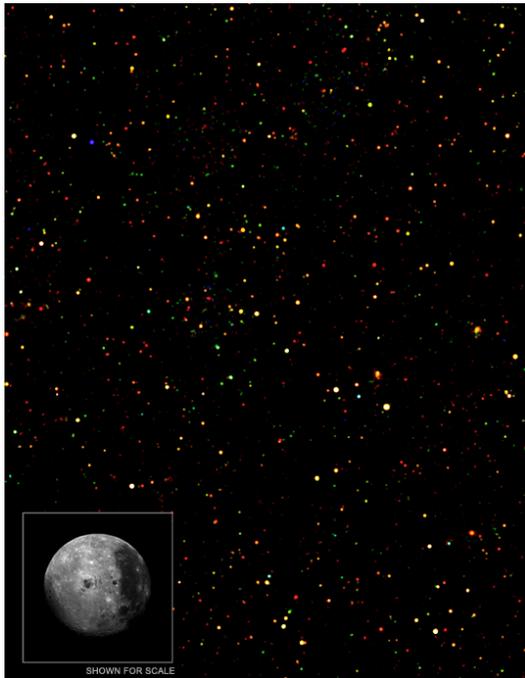
# AGN Surveys



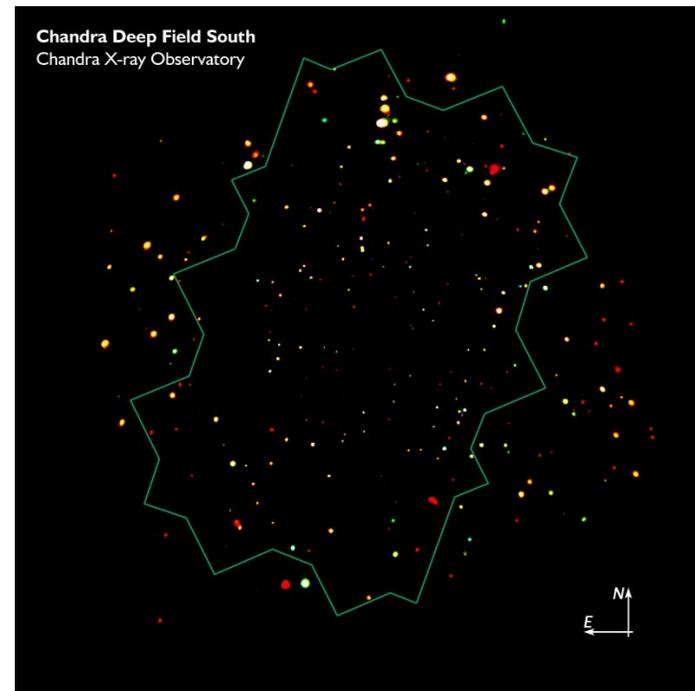
# Extragalactic Survey



- The epoch where hard X-ray source population (largely obscured AGN?) peaks and its evolution are largely unknown



NDWFS Boötes Field  
9 deg<sup>2</sup>  
8 month survey

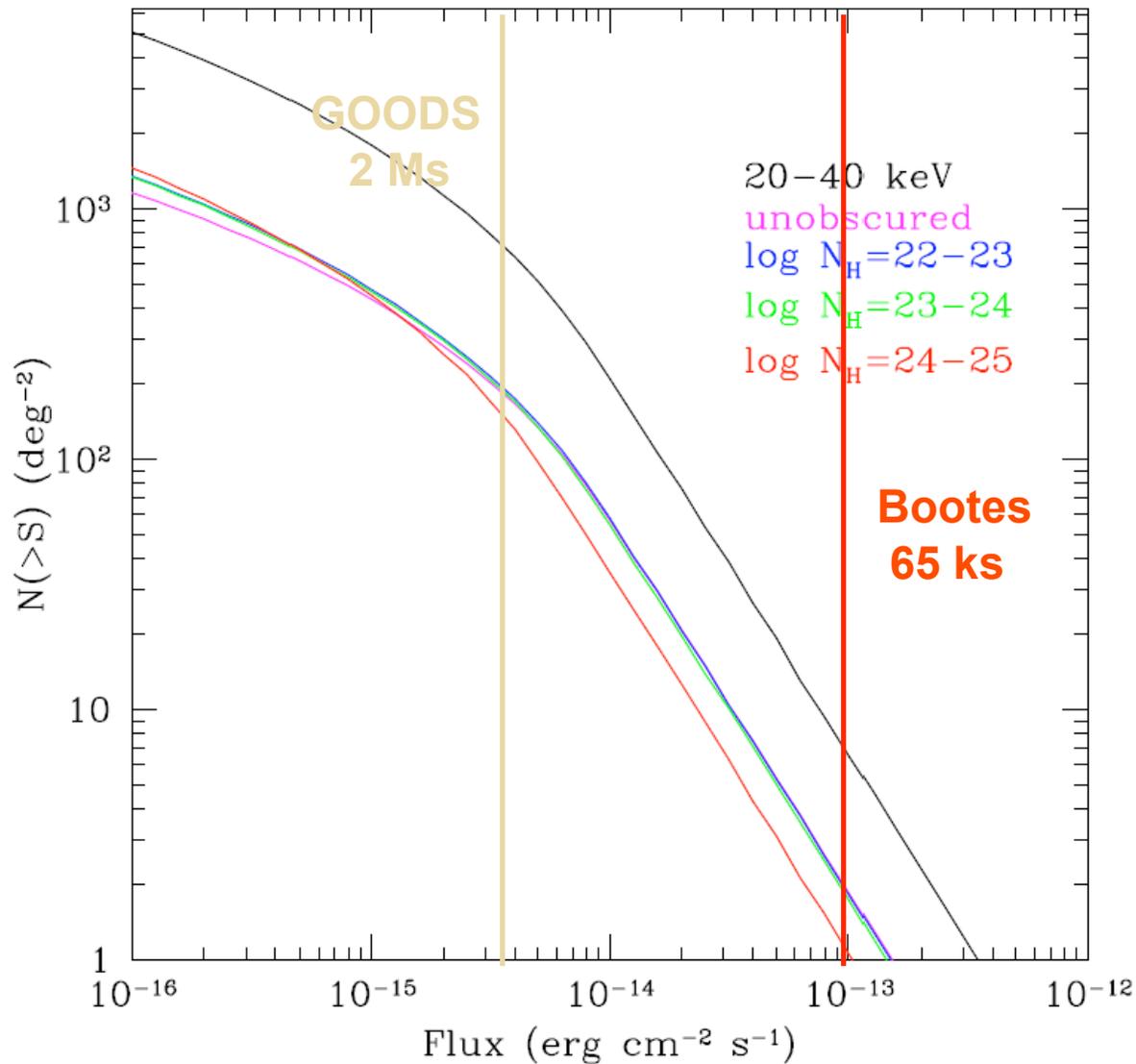


Chandra Deep Field South  
Chandra X-ray Observatory

GOODS Fields  
300 arcmin<sup>2</sup>  
3 month survey



# Sensitivity limits



Bootes  
10-40 keV:  
 $F_{\text{lim}} = 10^{-13} \text{ erg cm}^{-2} \text{s}^{-1}$

GOODS  
 $F_{\text{lim}} = 3.5 \times 10^{-15} \text{ erg cm}^{-2} \text{s}^{-1}$



## Summary



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- Cluster non-thermal emission
    - For large diffuse halos NuSTAR would clearly detect ( $>30 \sigma$ ) emission at the claimed level of SAX/RXTE
    - Distinguish between true non-thermal component and temperature structure in gas
    - Map the distribution of detected excess in Ophiuchus
  - Relics
    - Significantly better (factor  $\sim 10$ ) flux limits can be placed, lowering  $B_{\min}$ .
    - Combined with new low-frequency radio telescopes map same electron population in radio/HXR [330 MHz corresponds to 60 keV]
  - AGN Survey
    - Deep and wide FOV surveys planned. Deep fields will resolve  $\sim 50\%$  of CXB (10 - 40 keV)
  - Lots of other science (SNR, galactic survey, AXP.....)